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Use of Vibrational Optical Coherence Tomography to Characterize Corneal Biomechanics in Health and Disease

Abstract:

Vibrational Optical Coherence Tomography (VOCT) is a new non-invasive technique that provides an image based upon infrared light reflections from ocular components and simultaneous analysis of acoustic sound vibrations. The technology provides information to study the structure and mechanical properties of the cornea and other ocular tissues. Using this method, optical coherence (OCT) images are separated into low (green), medium (blue), and high pixel (red) intensity images to study the qualitative cellular (green) and collagen (blue and red) concentrations. In this manner the locations of cellular and collagenous components in diseased corneas can be visually observed. Pixel intensity versus depth plots can be obtained by scanning the green, blue, and red images providing quantitative data on the location and relative concentration of tissue components. OCT images of control corneas and subjects with keratoconus (KC) demonstrate differences in their distribution of cellular and collagenous components. KC corneas demonstrate a loss of collagen fibrils in the central part of the lamellae in the anterior and posterior stroma. The apparent loss of collagen fibrils in the anterior KC central stroma results in decreased infrared light reflections midway between Bowman's layer and Descemet's membrane. The loss of collagen and cellular reflections is associated with a decrease in the elastic modulus of the central portion of the cornea while the elastic modulus of the lower cornea is found to increase. Results of a simplified finite element analysis of control and stage IV KC corneas suggests that the strain is maximized in the central portion of the corneas where the stress concentration and resulting strain is highest. Elastic modulus and strain calculations suggest that the strain in the central region of Stage IV KC corneas is about 1.4 times the strain for the central portion of the controls. We hypothesize that the increased strain associated with a decreased modulus (stiffness) leads to cone formation in the central or paracentral region of KC corneas. We conclude that slippage in the collagen fibrils near the corneal-limbus junction leads to cone formation at or near the central cornea. The curvature as well as the stress concentration and strain are maximized at the central cornea promoting cone formation. The use of VOCT to evaluate changes in the structure of the anterior and posterior segments of the eye may provide a better understanding of the pathogenesis of ocular diseases such as glaucoma and macular degeneration.

Biography: Dr. Frederick H. Silver is a Professor of Pathology and Laboratory Medicine at Robert Wood Johnson Medical School, Rutgers, the State University of New Jersey. He did his Ph.D. in Polymer Science and Engineering at M.I.T. with Dr. Ioannis Yannas, the inventor of the Integra dermal regeneration template, followed by a postdoctoral fellowship in Developmental Medicine at Mass General Hospital in Boston, MA with Dr. Robert L. Trelstad, a connective tissue pathologist. Dr. Silver invented vibrational optical coherence tomography (VOCT) in his lab at Rutgers. US and European patents have been granted on a VOCT instrument and on vibrational evaluation of materials and tissues.